Focusing electrical current at depth

Andy Adler[1], Pablo Nery[2]
[1]Carleton University, Ottawa, Canada, [2]University of Ottawa Heart Institute, Ottawa, Canada

Introduction

During ablation, current must penetrate deeply into tissue to deposit energy; to achieve this, electrodes must be spaced further apart, affecting more tissue than necessary. We propose a strategy to focus current at depth using multiple surface electrodes and an optimal current-drive strategy. Simulation results in 2D are shown.

Catheter ablation is a minimally invasive procedure to destroy abnormal tissue. Radiofrequency catheters apply electrical energy to arrhytmogenic sites on the endocardium, as a therapeutic technique for atrial fibrillation (AF).

Currently, catheters have two electrodes for current application, and modern designs typically use advanced features such as open saline irrigation which cools the surface of the heart muscle [1]. To be effective current must penetrate sufficiently deeply into the tissue so energy reaches the entire ablation site. However, in order to penetrate sufficiently deeply, electrodes must be spaced further apart.

We are motivated by the need to achieve deep current penetration, while still maintaining a narrow width of application. Our proposed approach is to use multiple surface electrodes and calculation of an optimum pattern.

Methods

Using EIDORS, a model of a 2D homogeneous half space with 11 surface electrodes is created (left). An ROI is identified (green box) in which it is desired to have uniform current density magnitude, $|\vec{J}|$. On each side of the ROI, a region $\overline{\text{ROI}}$ is identified where is desired to have $\vec{J} = 0$.

Using 11 electrodes, $11 \times 10/2 = 55$ pair-drive current patterns are possible. For each pattern, i, the forward model is solved to calculate $\vec{J}_i$ in the domain.

In order to calculate an "optimal pattern", $\mathbf{c}$, we seek the value of current to be applied through each pattern, c_i. A Jacobian (sensitivity) matrix, $\mathbf{J}$ is calculated via vertical concatenation of each vector component of $\vec{J}$. $\mathbf{c}$ is calculated:

$$\mathbf{c} = \left(\mathbf{J}^t\mathbf{J} + \lambda\mathbf{I}\right)^{-1}\mathbf{J}^t\mathbf{d}$$

where λ is a Tikhonov factor, and $\mathbf{d}$ is set to 1 inside the ROI and 0 in $\overline{\text{ROI}}$.

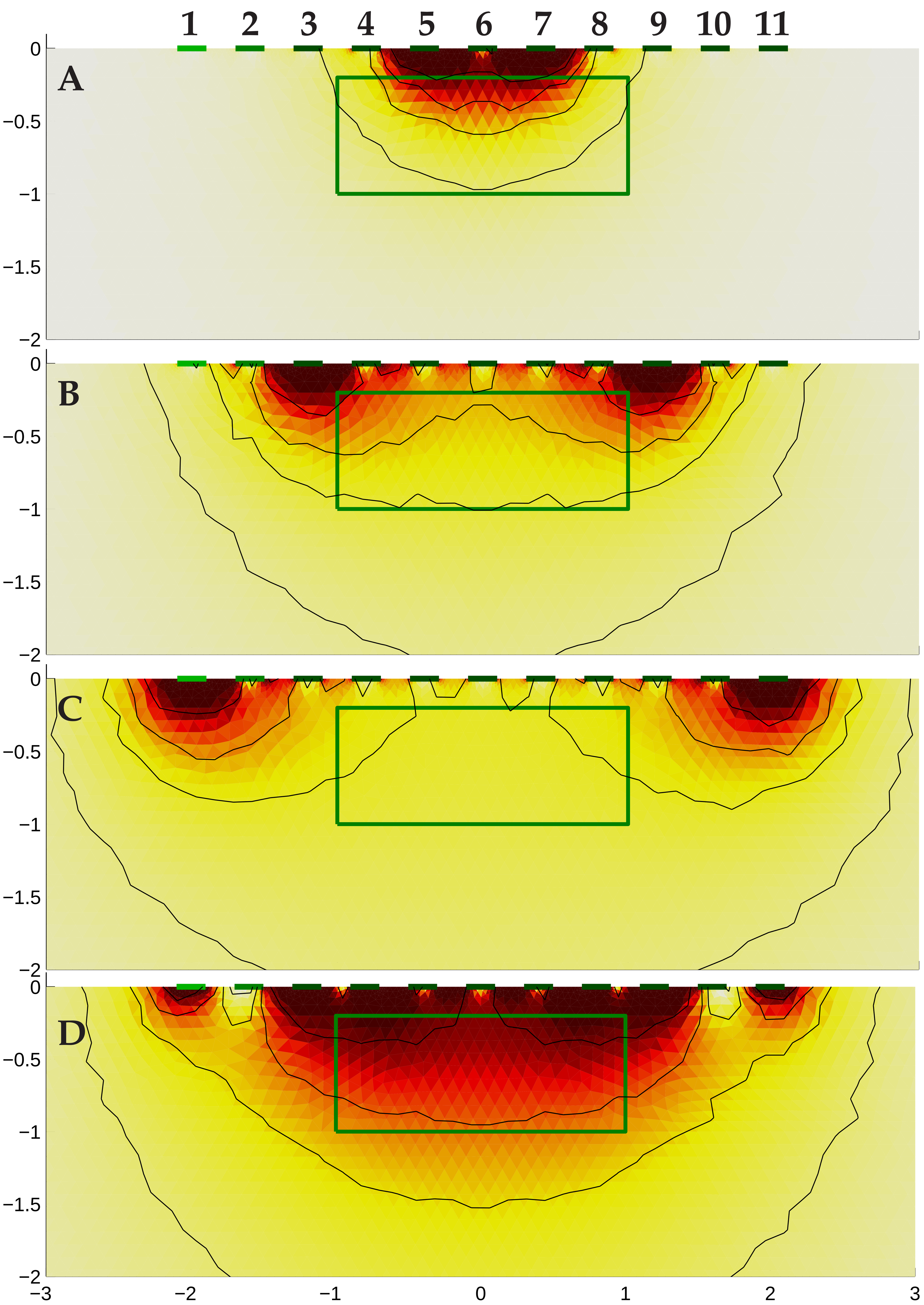
Discussion

Previous data[2] show that bipolar ablation is feasible in vivo. However, the technology used in circular catheters is limited to ablation within the atria. The present model has the potential to improve ablation technology with linear ablation catheters, resulting in an increase ablation lesion size and depth with wide clinical applicability.

These simulation results are promising and suggest that it may be possible to achieve improved ablation performance using multiple electrodes with optimized current patterns.

Results

The figures show three bipolar patterns (with the classic depth-width trade-off) and the "optimized" pattern for the identified ROI. A more uniform current in the ROI has been achieved, in this simplified, 2D model.



Current density vs. depth for four different current drive scenarios (darker colours indicate higher current). Contours indicate 5%,10%,15% and 25% of maximum. Electrodes: A) 5→7, B) 3→9, C) 1→11, D) optimized pattern (all electrodes).

References

[1] MC Wijffels, M Van Oosterhout, LV Boersma *et al*, " Characterization of in vitro and in vivo lesions made by a novel multichannel ablation generator and a circumlinear decapolar ablation catheter." *J Cardiovasc Electrophysiol* 10:1142–8, 2009

[2] H Nakagawa, Wittkampf FH, Yamanashi WS, *et al*, " Inverse relationship between electrode size and lesion size during radiofrequency ablation with active electrode cooling." *Circulation* 98:458–65, 1998.